Design Methodology of Production Improvement at "X Hydroponic Farm"

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Abstract — *According to "X Hydroponic Farm" facilities, a 40 x 60 square feet farm, with a capacity of producing 750 plants weekly; and actual production rate of 250 plants a week, is expecting a demand increase of approximately 60%. However, no capital or initial investment is available. Therefore, actual harvest process needs to be analyzed in order to identify significant factors that could impact productivity, maximize its business capacity and produce the new demand consistently. Therefore, a DMADV (Define, Measure, Analyze, Design, Verify) methodology was followed during the process to achieve goals and customer satisfaction.*

Key Terms *— DAMDV, Hydroponics, Improvement, Production Increase.*

PROJECT STATEMENT

In Puerto Rico, the 83% of agriculture is being imported from different locations around the world because of its low prices [1]. However, Puerto Rico has one of the best climates for agriculture. Therefore, Puerto Rico needs to produce and grow products for local consumption and exportation. Agriculture has been evolving during the past years and technology may be incorporated to reduce operational costs and process efficiently. During the last years hydroponics has been a key and evolving process type of agriculture. However, this technique is a completely manual operation with a variety of opportunities to improve. Some of these opportunities are related but not limited to:

- Product growth.
- Balanced and optimum irrigation.
- Sun light level/exposure.
- Water levels (i.e. How long does plant/product need to be in water).
- Nutrients balance.
- Water purity.
- Farms Layout.
- Production Monitoring.

"X Hydroponic Farm", and agricultural business located in de central area of Puerto Rico, is a small business with short resources. Its owner started two (2) years ago looking forward to expand the business. Currently it holds a 40 x 60 square feet facility and production capacity of 750 plants weekly. However, its current demand is of 250 plants weekly. The owner of "X Hydroponic Farm" is expecting an increase in demand and no capital nor is initial investment to prepare for the upcoming demand available. Therefore, opportunities within current process need to be addressed.

RESEARCH DESCRIPTION

Search for current and new technology, different processes, and mechanisms using different applied sciences tools to be incorporated in agriculture, mainly in hydroponic systems. This will lead to an efficient agriculture production and hydroponic systems among the industry.

RESEARCH OBJECTIVES

The main objectives of this research are:

- Review current vs new technologies within the "X Hydroponic Farm".
- Design mechanisms to improve production and/or reduce waste time.
- Implement applied sciences tools such as Lean and Six Sigma to increase productivity at "X Hydroponic Farm".

RESEARCH CONTRIBUTIONS

The contribution of this research will result in proposal mechanisms and implementations to increase productivity. This will lead to a better production and product quality. In addition, time will indirectly address because the introduction of applied science tools will reduce human effort within the processes and systems. Also, it relates benefits with money because processes will become efficient and financial benefits will be seen. Therefore, contributions of this research will result more efficient process in which profit, customer satisfaction, and employee's engagement will be reflected.

LITERATURE REVIEW

During the early centuries of Spanish rule in Puerto Rico, agricultural operations were headed by farms, cultivating sugar cane and other products. They were not large-scale operations, but produced enough for local consumption. In the nineteenth century (XIX), the "Real Cedula de Gracia", which promoted the economic and trade growth, larger farms emerged. Puerto Rico was one of biggest countries with the best agriculture profile in the world. This is because each agricultural product requires special conditions of soil, topography, temperature and humidity for that a good harvest to occur. These factors change significantly by region; therefore, due to the climatic and topographical variations of Puerto Rico, which is an advantage, it allows a big agricultural diversity. In Puerto Rico, the best lands for cultivation are on the borders of the coastal plains.

The north area of the central mountain range receives adequate rainfall most of the year. Therefore, the coastal plains and the humid northern hills encouraged the cultivation of sugar cane in the first half of the twentieth century. In addition, cool temperatures have favored the mountainous interior products such as coffee, citrus, and other fruits snuff. Currently, livestock activity was limited and affected by the expansion of the urban industry. The south area of the Central Mountain Range is a coastal plain that extends continuously from Patillas to Ponce. Another area that has very fertile land in the Southwest is in the plains between Lajas and Guánica, but is characterized by a much more low rainfall than the north.

Coffee gained commercial importance during the second half of the nineteenth century, when it was exported to the European countries and the United States. In these markets, coffee enjoyed a great acceptance among fans of this product. Although coffee cultivation has taken off in recent decades, cyclonic phenomena of recent years have severely affected many farms in the mountainous region. In 1996 and 1998, Hortensia and Georges cyclones, respectively, significantly affected the production of coffee. It is estimated that it will take some time to achieve production levels increase.

The more developed operations were located in the area of the southern coastal plains; including sugar mills situated at Aguirre and Guánica. These centers of sugar production became an essential part in the life of the villages that depended on this industry. During harvest, the plant operated without pause, around the clock, to maximize production. But, during a time when finished cane production, workers had to be employed in other jobs to survive.

Starchy, like bananas, plantains and roots such as cassava, yam and sweet potato, play an important role in the agricultural economy of Puerto Rico and were an essential part of the Puerto Rican diet. These products, which are grown in mountainous areas, today, replace sugarcane, especially in the coastal plains of the north and south.

In 1950 agriculture generated 36.2% of total employment in the country. Sometime during the 1960s, both in absolute and relative terms, agriculture was no longer the biggest employer in the economy of Puerto Rico. The proportion of employment that brought agriculture fell to 22.8% in 1960 and 9.9% in 1970. During the last three decades of the twentieth century and early twenty-first century, the downward trend continued; in fiscal year 2005 there were only 26,000 people formally registered in the agricultural sector, representing only 2.1% of total employment [2].

Agriculture and education about it needs to grow exponentially among “puertoricans” because it will be crucial to the Puerto Rico’s economy and wellbeing of their habitants. Recently, there have been seen a boost of agriculture themes an activities among different organizations whom are promoting it. There are different ways help farmers and agriculture in Puerto Rico, from economy to improves technics. This research will address how engineering and technology could impact the agriculture sector providing to farmers improves processes, technology equipment. In addition it will consider how to change the mentality of young people in order to motivate them so that they could be engage in a cultural change which promotes agriculture and all of its benefits.

METHODOLOGY

In this design project the methodology that will be used is will be DMADV. DMADV is an acronym which means: Define, Measure, Analyze, Design and Verify. DAMDV is an innovation approach used for design and implement new services, products or process. It is also mostly useful to implement new initiatives, or strategies to accomplish planning goals [3].

- **Define Phase:** It consists in defining the scope, goals and project statement. It also requires a project charter describing the actual process and team players. This charter is normally represented in an A3 format.
- **Measure Phase:** The purpose of this phase is to present the actual data and key aspects of current process and or situation. It also presents what exactly does customer are looking with the new initiatives and what does the new system needs. Common tools used in this phase to present the current state are paretto charts and process flow diagrams in order to identify the specific path to attack during the project.
- **Analyze Phase:** During the analyze phase the key components are to include, the probable root causes, value and non-value added analysis of that could prevent to achieve goals. This analysis mostly presented a cause-effect diagram. In addition, possible solutions to address the opportunities found during the analysis and root cause identification are mentioned and established.
- **Design Phase:** This phase includes a high level and detailed design for selected alternatives during the analyze phase. In addition, an effort to identify where errors may occur and address them through modifications is where findings improvements are implemented using a variety of tools.
- **Verify Phase:** This final step involves piloting the new product or service, gathering data and evaluating performance, satisfaction, or results. Based on the data, any final adjustments are made. A plan is developed and implemented to transition the product or service to a routine operation for the organization and ensure that the change is maintained. Finally, lessons learned in the DMADV process are documented.

RESULTS AND DISCUSSION

The next sections describe the problem analysis and improvement results following the Lean Six Sigma Methodology and DMADV tool.

Define Phase Analysis

To achieve the objectives of this research, the methodology to be used is DMADV. This methodology is a process improvement tool linked to Six Sigma. In addition, it consists of the following five phases:

Problem Statement

The owner of “X Hydroponic Farm” is expecting an increase in demand and has no capital or initial investment to prepare for the upcoming demand. Therefore, opportunities within current process need to be addressed.

Project Goal

The project goals for this design project will be centered in prepare the "X Hydroponic Farm" facilities and process for production increase.

Project Y

Project Y of this design is focused in a production increase for "X Hydroponic Farm". In addition, a waste time reduction, production monitoring, and human effort activities which are indirectly reflected to a production increase.

Scope

The scope of this project will apply for "X Hydroponic Farm" harvesting process. The scope will exclude other farms and raw material (crops).

Benefits

Soft savings will include a reduction on human effort activities and a visual aid for constant monitoring of production.

Measure Phase

As part of the measure phase, different tools where used to show actual status of the "X Hydroponic Farm". These tools include process flows, parretto charts demonstrating products harvested at the farm and its productivity. In addition, the hydroponic system used in the farm is represented.

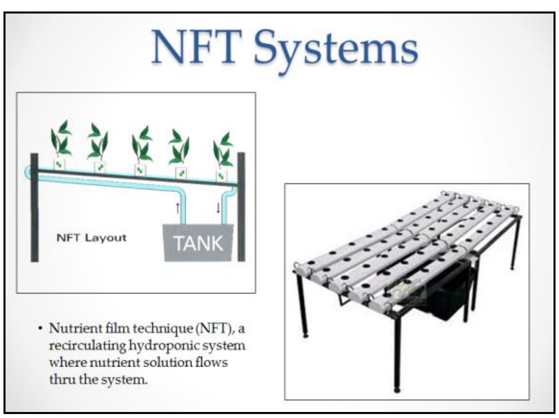

Figure 1
NFT Systems Overview

The overall advantages of NFT hydroponic systems include the efficiency of nutrient delivery, continuously available nutrition and automatic circulation and aeration of the nutrient solution [4]. These systems are also some of the least expensive to set up and maintain. NFT systems are easily customizable to any shape or style of garden, which means no limit when it comes to room and lighting configurations. However, the main disadvantage of the NFT system is the limited space for the root mass. This, in turn, limits the size of the plants that can be grown in the system. The continued delivery of moisture is advantageous during vegetative growth but can cause less-than-optimal growth or some fruiting or flowering plants.

"X Hydroponics Farm" mainly produces three (3) green products which are sold to local cafeterias and food trucks. These products are, Puertorrican Lettuce, Roman Lettuce and Corainder. Its biggest demand is Puertorrican Lettuce (Refer to Figure 2 for a paretto chart illustrating actual product demand).

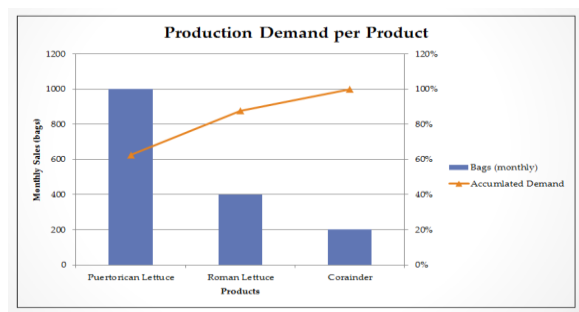

Figure 2
"X Hydroponic Farm" Actual Product Demand

The actual process flow for "X Hydroponics Farm" consist of germinating seeds, transporting them to another site for harvest (or placed into oasis) and finally gathering the crops. A more detailed process flow is represented in Figure 3.

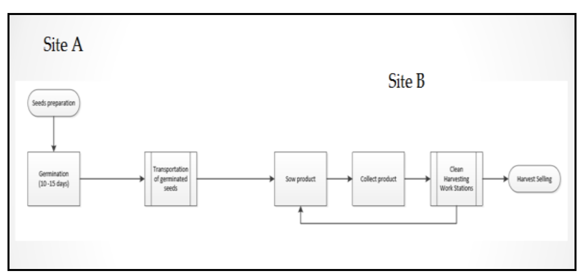

Figure 3
"X Hydroponic Farm" Actual Process Flow

"X Hydroponic Farm" production facility with about 1,800 ft2 and a production capacity of 750 plants weekly and 3,200 plants monthly. Actually this farm has a demand of approximately 1,600 plants which represents a use of 50% of its capacity. Therefore, one of the main goals of a production facility is to maximize its productivity. This depends upon several factors, such as the kind and the complexity of the product produced, the quality of the raw materials, the complexity of the process and the arrangement of the workstations constituting the production process. Some of these parameters are determined by the product and, for this reason, are unchangeable; others, however, are variable and thus improvable. Figure 4 represents an overview diagram of "X Hydroponic Farm" layout and work stations arrays which consist of four (4) lines and five (5) work stations each. In addition, Figure 5 represents a more detailed diagram per line.

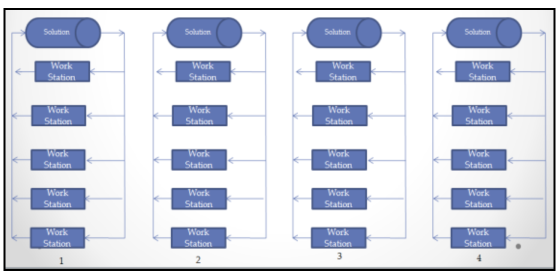

Figure 4
"X Hydroponic Farm" Production Line Diagram

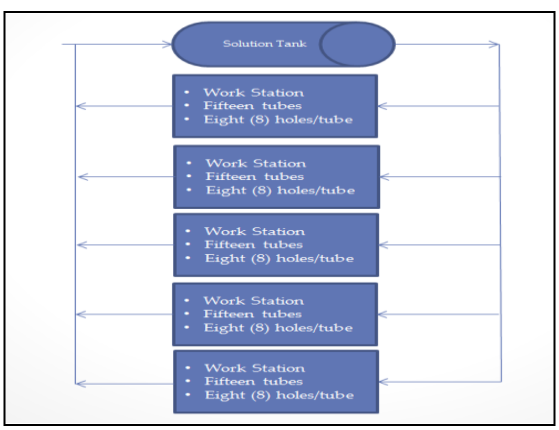

Figure 5
"X Hydroponic Farm" Detailed Line Diagram

Analyzed Phase

The analysis focuses on identification of the different approaches that could be used to meet customer or stakeholder/investor requirements. Key functions within the requirements are prioritized. Alternative methods and processes are developed based on prioritization of these functions. Finally, several alternatives are evaluated, and the most effective alternative, based on the best parts of the best concepts, is selected for Design. This analysis is focused on the team reviews, data collection plan and customers desire ideas. Team members are focused on fiddling opportunities to reduce the waste time among the process and to reduce the human effort activities when cleaning the system.

Results of customer and team discussions, and site reviews reflected a variety of opportunities that should be addressed in order to achieve the goal. Some of these opportunities are represented in below figures.

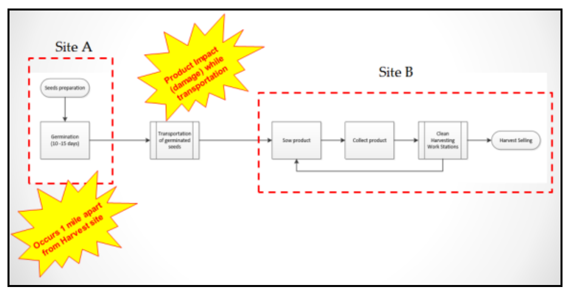

Figure 6
"X Hydroponic Farm" Process Flow with Identified Deficiencies

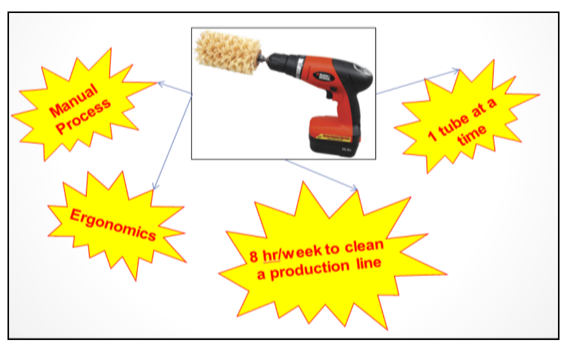

Figure 7
Tool Used for Work Stations Cleaning

As part of the analysis a process capability was executed. Analysis revealed that actual process is capable to assume a bigger demand and increase productivity (refer to Figure 8 for process capability analysis). However, because the main goal of this project is to improve productivity for "X Hydroponic Farm" next project phase, a new means and lower control limit was proposed.

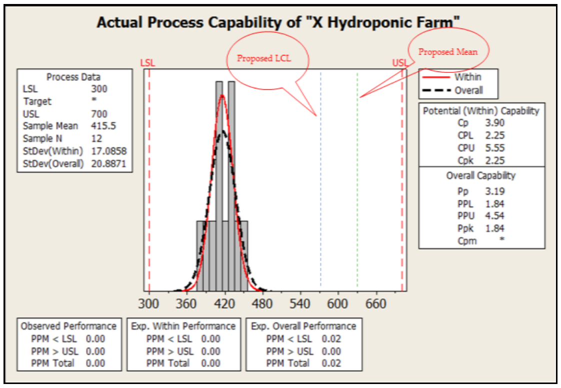

Figure 8
Process Capability Analysis

Even thou analysis shows a capable process, the team decided to analyze and present the different opportunities disused to produce efficiently, reduce human effort and monitor weekly production; in addition to the proposed limits and means. Therefore, a cause and effect diagram of the "X Hydroponic Farm" with identified elements that may impact the productivity of the customer in its next project and demand. Refer to below figure (Figure 9) for cause and effect diagram.

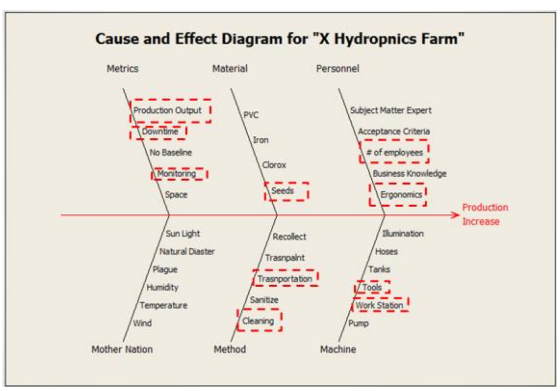

Figure 9
Cause and Effect Diagram

As shown in the cause and effect diagram, there are a variety of significant factors (x's), within the process in analysis, that could impact the in a negative way for a production increase [5]. The team analysis revealed that the significant factors to be addressed during this project will be as follows:

- Metrics
  - Production Output
  - Monitoring
  - Downtime
- Method
  - Transportation
  - Cleaning
- Machine
  - Tools
  - Work Station
- Personnel
  - Ergonomics
  - # of employees

Design Phase

"X Hydroponic Farm" is a 40 x 60 square foot facility with a weekly capacity of approximately 750 plants. However, actual demand is approximately for a 250 plants a week. "X Hydroponic Farm" is planning to increase productivity for its new demand which will cover its capacity. It is administrated and labored by one employee (the owner). The employee duties go from germinating seeds to distributing crops. Therefore, analysis revealed that waste time and other factors such as human effort activities needed to be reduced to maximize its capacity and achieve the goal. Because the goal of this project is to increase productivity, solutions will be designed and proposed to address opportunities.

Per executed analysis, one of the key factors that need to be addressed is the waste of time because of the transportation [6]. Therefore, a new facility layout was designed and proposed to include germination process within the facility. The proposed layout will reduce 30min of travel and transportation between germination site and harvesting site. In addition, by germinating within the same facility product lost and possible damage will be reduced. This will reduced the loss of crops during harvesting cycle. Therefore, by relocating the germination table to the harvesting site, an increase in productivity is expected.

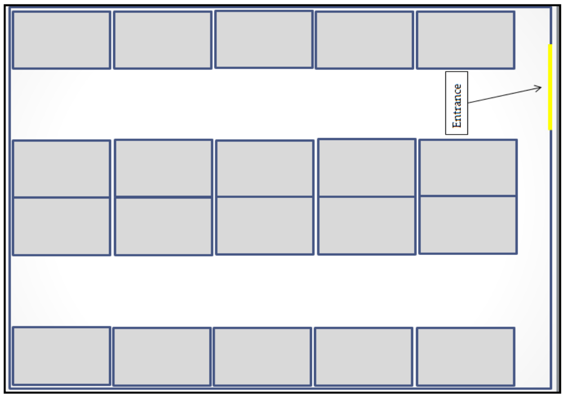

Figure 10
Current Facilities Layout

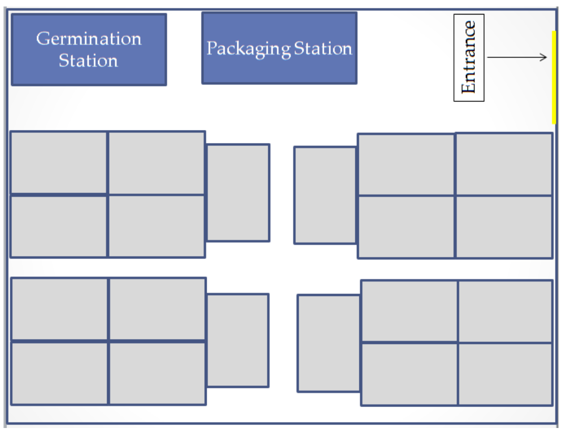

Figure 11
Proposed Facility Layout

Another area of improvement analyzed was production monitoring. The "X Hydroponic Farm" didn't have any log or history data regarding earlier modification and changes done previously. In the other hand, didn't have any monitoring process to log its weekly production, yield and downtime. Therefore, an excel sheet was prepared to in order to continuously valuate business performance to find areas where business performance could be improved. This design will help the owner to:

- Implement actions in areas where its performance should improve.
- Monitor and log actions taken to improve performance.
- Track production line and germination station performance.
- Identify losses from breakdowns, changeovers, setup, etc.
- Identify the root causes for machine or line stoppages.
- Manage limitations to optimize capacity.
- Cost justify spending on new equipment.
- Trial process improvements before implementing new ideas or designs.
- Rapid response to stoppages and production disturbances.

During analysis phase and team discussions, the time to clean work stations was identified as another key contributor that could negative impact production increase. Why? because "X Hydroponic Farm" owner spends 8 hours weekly to clean one production line. Its current cleaning method is a complete improvised manual process in which hands drill and brush is used to clean hole per hole in a work station. A research for cleaning tube technologies systems was executed. However, findings were unsuccessful. Current cleaning tube systems are design for closed tubes in which the cleaning systems is driven by flow pressure inside the tube. Therefore, because NFT hydroponics consist of round tubes with holes on top, reviewed cleaning systems were not appropriate. In the other hand, additional manual systems were reviewed; however, no big difference was seen between the actual and the reviewed manual systems.

The team decided to design an NFT hydroponics cleaning mechanism in which interaction between the cleaning cycle and the operator was minimal. This mechanism allows users to interact only during the load and unload cleaning phase. The system is placed in one end of the of the work station. It has the capacity to rotate while displace in order to clean the entire tube length. The system will consist of a nylon brush (6 inches length and 2 inches diameter) attached to a sectioned shaft which will rotate while is displaced. The shaft will be powered by a small electric motor with the following specification. The implementation of this mechanism will separate the operator from the work station cleaning phase. Therefore, the cleaning time will be reducing up to a 50%.

Verify Phase

The given proposals of different alternatives to prepare the "X Hydroponic Farm" for its expected demand increase were successfully agreed with business' owner. Proposed facility's layout was initiated and benefits will be seen as it is completed. With the new layout business' owner will be able to have the germination table within the same facility. Moreover, free space is available for a packaging station which used to be done on top of an improved table in facilities surroundings. This improvement will reduce 30 minutes' drive and transportation of germinated seeds. Those 30 minutes before spent in transport, will now be used for other activities within the facility. Furthermore, a weekly production sheet was developed to monitor production and identify possible opportunities within the process. Finally, a tube cleaning mechanism was design to reduce by a minimum of 50% of the cleaning time. However, because no capital or initial investment was available, no prototype was developed.

CONCLUSION

The main objectives of this design project/research were successfully achieved. Because of the results reveled by the analysis, a new layout was designed and proposed in order to include the germination process in the same facility. Moreover, a packaging table was able to be introduced in the facility. In the other hand, while no transporting the seeds, these are not exposed to damage or other vulnerability. Furthermore, no production monitoring process was in place. Therefore, a weekly production sheet was developed in order to track daily activities and weekly production. This sheet will help the owner implement actions in areas where its performance should improve, monitor and log actions taken to improve performance, track production line and germination station performance among others. Also, it will have historical data to evaluate trending and abnormalities. As part of the "X Hydroponic Farm" growth, it is listed to receive government funds. Once funds are received, cleaning mechanism mentioned before and other automated initiatives will be evaluate and analyzed for implementation.

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